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Applications of Computational Fluid Dynamics Simulations in Urban Environments and Experiments Designed to Aid the Development and Evaluation of these Models

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Applications of Computational Fluid Dynamics Simulations in Urban Environments and Experiments Designed to Aid the Development and Evaluation of these Models

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Abstract

Progress in development of CFD models has shown their great potential for prediction of air flow, heat dissipation, and dispersion of air pollutants in the urban environment. Work at Lawrence Livermore National Laboratory has progressed using the finite element code FEM3 which has been "massively parallelized" to produce flow fields and pollutant dispersion in a grid encompassing many city blocks and with high resolution. (See the related papers in this Proceedings). While it may be argued that urban CFD models are not yet economical for emergency response applications, there are many applications in assessments and air quality management where CFD models are unrivaled in the level of detail that they provide. We have conducted field experiments to define the flow field and air tracer dispersion around buildings as a means of critiquing and evaluating the CFD models. The first experiment, the "B170 study", was a study of flow field, turbulence, and tracer dispersion in separation zones around a complex, single building. The second was the URBAN 2000 experiment in downtown Salt Lake City where flow fields and tracers were studied in nested resolution from the single building scale up to larger scales of 25 city blocks, and out to 6 km. For the future an URBAN 2003 experiment is being planned. We review the salient features of these experiments.

A "breakthrough" technology in urban diffusion modeling is the use of *modified* computational fluid dynamics models (CFD) that use the meteorological conventions of large eddy simulation to represent the flow field (1). These CFD models have been initialized from the output of mesoscale atmospheric models with 4 km grid resolution, apparently with no problems although questions remain about aliasing and sources of bias. While more work remains, it is clear that should progress continue a remarkable tool should be available for such applications as:

- Vulnerability studies for chemical, biological, and nuclear terrorism
- Assessments of air quality for urban pollutants—CO, NO, O_3, and particulates
- Preparing for disease outbreaks which are transmitted by wind
- Inhalation exposure attribution downwind of industrial releases
- Mitigation of susceptible populations of exposed individuals

- Mitigation of problems *inside buildings* through heating and ventilating intakes
- Planning for emergency response where scenarios may be studied beforehand

Simulations and experiments in these complex cases have been made to interact. We have used rough case studies with CFD models to plan the experiment (2,3). That is, since measurement resources are limited they should be placed where we should get the most gain in developing or evaluating the models. Eventually the knowledge about the urban atmosphere is summarized and tested in the models. Of course, we have utilized wind tunnel or water channel data to evaluate the models as well. But the large scales of motion in the atmosphere and the complex urban heat island and turbulent wake mixing in real urban settings have made it necessary to have prototype experimental data.

Urban meteorology or *urban fluid mechanics* is an evolving field (4) with many challenges to define the surface boundary layer and thermal influences. But the need is great with so many people living in the urban zones, and there will be an eventual demand for the weather forecasts to be made for specific land use zones (5).

B170 Experiment. We conducted a series of experiments in 1999 and 2000 at a complex building, B170 (the National Atmospheric Release Advisory Capability housing the Atmospheric Sciences Division and the Energy and Environment Directorate) at Lawrence Livermore National Laboratory (6). B170 is a 3-story building with a courtyard, a tangentially-sited auditorium, and alcoves along its side. We used arrays of sonic anemometers to map the horizontal flow-field below the mid-height of the building for a range of inflow wind directions. Approximately 50 anemometer locations were recorded. We also have one-second turbulence files for 6 locations along the building sides. Generally speaking, we have the more detailed flow-field data for wakes and separation zones than for well-behaved flows along parallel walls. In 2000 we utilized the air tracer SF_6 to determine concentration fields in separation zones along the ground. While these data are not extensive we were able to compare the results to output from CFD models with good results (7). In the case of flow vectors, the FEM3MP model was within 15% of vector magnitude when averaged over the whole domain. The model had less success with the separation wake in the lee of the building than with the side separation zones, however. The data from this study are publicly available for anyone with similar interests in model development and evaluation.

URBAN 2000 Experiment. In October 2000, a collaborative experiment was conducted involving more than 100 scientists, planned and led by a consortium (8) of three National Labs: Pacific Northwest National Lab (K. J. Allwine), Lawrence Livermore National Lab (J. H. Shinn), and Los Alamos National Lab (G. Streit). The members of the Vertical Transport and Mixing Project (VTMX) provided the backbone of regional sounding data, while URBAN 2000 provided building scale data out to 6 km. This was a night-time experiment with 18 one-hour releases of air tracers carried out by NOAA Air Resources Laboratory Field Research Division (K. Clawson). Other participants were the UK Defence and Evaluation Research Agency (I. Griffiths) and a meteorology contingent from Dugway Proving Ground (C. Biltoft). At the "building scale" 45 tracer bag samplers, multiplexed gas analyzers, 12 2-D sonic anemometers, 2 3-D sonic anemometers, and 1 lidar density vertical profiler (Vaisala Corporation) were set up within one city block. At the "urban" scale (25-city blocks) were 64 tracer bag gas samplers, 1 mobile tracer analyzer, 9 wind stations, 3 2-D sonic anemometers, 6 3-D sonic anemometers, and 1 acoustic sodar. At the 1 to 6 km scale there were 36 tracer bag samplers, 4 mobile tracer analyzers, 6 wind stations, acoustic sodars, 1 radar wind profiler, 60 temperature loggers, and the *WindTracer* doppler lidar mapping the radial wind components from an observation location above the city. At the "regional" scale there was a mix of VTMX and URBAN 2000 participants who operated 50 tracer bag samplers, 1 mobile tracer analyzer, 32 mesoscale wind stations, 6 radar wind profilers, 7 acoustic sodars, 3 rawindsonde balloon sites, 4 tethersonde sites, 10 sonic anemometers, and a doppler lidar (R. Banta, National Center for Atmospheric Research) to determine cold-air inflow from canyons. Summaries of the VTMX Experiments (C. Doran) and URBAN 2000 Experiment (K. J. Allwine) are in process in the *Bulletin of the American Meteorological Society*.

These 18 tests constituting the Experiment were conducted 3 per night every other hour beginning 7 October and ending on 26 October. There were ten Intensive Observation Periods (IOP), six of which used SF_6 air tracer. The initial data analysis was agreed to be on IOP 10, and some of these results are being presented at the Conference. At this time, the URBAN 2 Experiments can be reviewed on the World-Wide Web through Lawrence Livermore National Laboratory Website, but the data are available only to those who participated and have been issued a password. Eventually, the collaborators will make this data available to the public after they have an opportunity to publish their own papers.

Planning the URBAN 2003 Experiment. A second large-scale experiment similar to the above is planned for 2003. The choice of cities has been narrowed to either Oklahoma City or Phoenix. The purpose of URBAN 2003 is to provided evaluation data for models where the boundary layer is a daytime, convective case. Much work remains to be done before the experimental details can be released but it is clearly going to involve many collaborators just as did URBAN 2000.

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